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Delineation of Ground Water Recharge Zones in Hard Rock Terrain of Tamil Nadu

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Ground water resources diminish at alarming rates in hard rock regions as it is the primary source of irrigation as well as domestic purpose. Periodic replenishment of ground water in these areas is only through rainfall. Delineation of potential groundwater recharge zones in hard rock areas is of vital importance to enhance the recharge. Conventionally, suitable zone for groundwater recharge is deciphered using hydrogeological, geophysical and geomorphological maps, which is often time consuming and uneconomical. But, the analysis of unconfined aquifer response in terms of rise in water level due to precipitation in hard rock areas is one of the rapid and cost-effective methods. Cross-correlation of rise in water level and precipitation is established for Parambikulam-Aliyar-Palar (PAP) basin of TamilNadu, India to delineate groundwater recharge zones. The entire area is classified into various recharge zones depending on coefficient of correlation. Thus, decisions on construction of recharge structures / optimal pumping in these areas can be decided for sustainable ground water resource management to meet future demands.

Key words: Hard rock, groundwater recharge, cross correlation coefficient, recharge zone delineation

Groundwater, a renewable resource is subjected to periodic replenishment primarily through precipitation. The only source of this exploited resource is rainfall, which is limited to a few monsoon months in a year, particularly in semi-arid regions of the country. According to an estimate, there is about 4.1-19.7 per cent of annual rainfall that replenishes groundwater in semi-arid regions (Rangarajan and Athavale, 2000). The annual rainfall is also often scanty and frequent drought occurs. Due to near-total utilization of surface water resources and frequent failure of monsoons, groundwater emerged as major source to meet the ever increasing demands of irrigation, industry and domestic sectors. This pattern is well demonstrated by the study on the usage of the deep bore wells for water supply schemes over a period of decade 1991-2003 which indicated that about 13.25 per cent of bore wells have lost their sustainability (CE, SG & SWRDC, 2003). In order to arrest the depletion in groundwater potential and achieve sustainability, several measures including artificial recharge are suggested. To implement artificial groundwater recharge, it is essential to delineate potential groundwater recharge zones. Conventionally, remote sensing, photo-geological, hydro-geological and geophysical methods are deployed to select favorable sites for implementation of artificial recharge scheme. These methods are indirect, time consuming and sometimes uneconomical, particularly, when one has to deal with large basin. Instead, a simple and rapid method to scan the entire area and arrive at suitable zones for artificial recharge is to be developed (Muralidharan and Shanker, 2000).

Materials and Methods

Study Area

The study area is situated in Parambikulam-Aliyar-Palar (PAP) basin of Coimbatore and Erode districts, Tamil Nadu, India (Figure1) which lies between 10°10'00" to 10°57'20" N latitude and 76°43'00" to 77 °12'30" E longitude. It is spread over an area of 1104.3 km^2. The basin has an undulating topography with maximum contour plain of 300m and maximum spot height in plain is 385 m above MSL. Geologically, the area is comprised of crystalline rocks of Archaean age. Hornblende-biotite gneisses occupy the major portion of the basin followed by intrusions of pegmatites and quartz, traversing the country rock in all directions. The average thickness of weathered zone is 9.3 to 10 m. The lineaments are traversing to a length of 10-15 in the central parts and eastern parts of the area. Several patterns of sheared and fractured zones are noticed along contact zones and also between varied geological formations. The intersections of lineaments are proven to be the potential zones, (Larson, 1984) for artificial recharge structures.

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Table 1. Average monthly water level fluctuation with average annual rainfall from 1988-2008

Month	Rainfall (mm)	W63705 (m)	W63703 (m)	W63708 (m)	W63709 (m)	W63710 (m)	W63716 (m)	W63717 (m)	W63718 (m)	W63719 (m)
Jan	7.00	5.65	12.01	0.47	4.05	3.91	6.44	5.88	8.85	9.09
Feb	7.08	5.87	12.88	0.46	4.40	4.07	6.97	6.79	9.56	10.45
Mar	27.67	6.47	13.27	0.49	4.62	4.08	7.36	7.40	10.12	10.85
Apr	56.51	6.72	13.44	0.50	4.71	4.59	7.91	7.84	10.75	11.05
May	71.75	6.95	13.29	0.52	4.85	5.68	7.90	8.29	11.80	12.13
Jun	77.14	7.06	13.52	0.52	4.87	5.88	8.15	8.48	12.27	11.46
Jul	162.27	7.15	13.55	0.53	4.49	4.75	8.06	7.58	11.76	11.74
Aug	83.06	7.45	13.38	0.56	4.14	3.93	7.00	6.99	10.74	10.92
Sep	35.45	7.59	13.70	0.55	4.11	4.01	7.03	6.31	9.34	11.00
Oct	153.00	7.62	13.87	0.55	4.26	3.97	7.34	6.01	9.71	10.94
Nov	132.85	6.74	12.43	0.54	3.88	3.70	6.37	5.81	8.91	10.22
Dec	41.34	5.81	11.90	0.49	3.81	3.78	6.45	5.65	8.18	9.58

The rainfall distribution in the study area is not uniform due to the presence of hills and changes in the topography. Hence the study area under Pollachi rain gauge station was delineated from the PAP Basin which comes to about 1104.3sq.kms. The observation wells located in the area represented by Pollachi rain gauge station alone were considered for the present study (Fig.1).

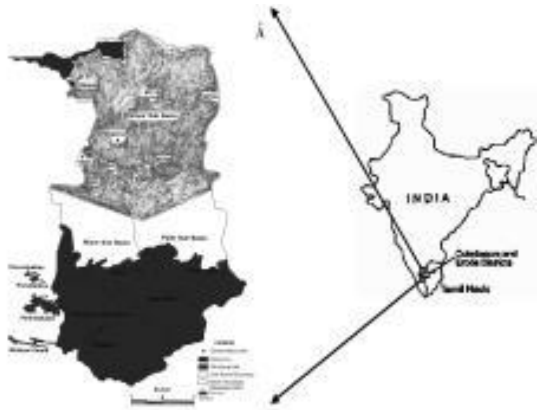

Figure 1. Location map of study area in PAP basin

The monthly water level data recorded for 21 years by Public Works Department (PWD) for nine wells in the study area (1988-2008) were considered for the analysis. The cross correlation between rainfall and depth to water level measured in different months from January 1988 to December 2008 were determined. The correlation coefficient of these parameters varies from place to place and time to time. There is a significant rise in water levels due to rainfall in the months of July, October and November. An attempt was therefore made to correlate the water level variation due to the monsoon rainfall during the months of October to January.

The mean annual rainfall for the period from 1988 to 2008 varied from 462.3mm (1995) to 1343.2 mm (2005) (Figure 2). The mean annual rainfall works out to 862.11 mm for this period.

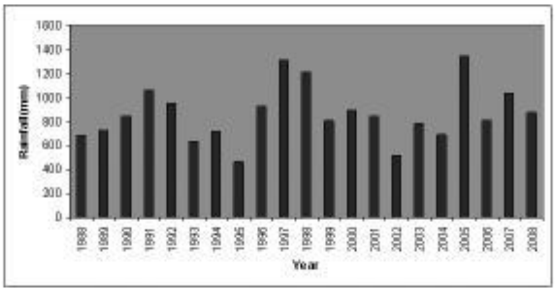

Figure 2. Mean Annual rainfall of Pollachi rain gauge station (1988-2008)

In the case of mean monthly rainfall, 4 distinct rainfall occurrence patterns were observed (Figure 3) in a year: Jan to March, April to June, July to Sept and Oct to Dec. Further, the last quarters viz. July to Sept and Oct to Dec, brought almost 71% of the annual rainfall and this is mainly due to south west followed by north east monsoons.

The long term hydrographs (1988-2008) of the observation wells show depletion in groundwater levels (63716, 63718, 63719) ranging from 6.0 m to 12.0 m. The maximum fluctuation of groundwater levels in all the observation wells range from 2.0 m to 5.0m.

The water level hydrographs with rainfall data is plotted and it can be seen that there is approximately a time lag of one/two months in the response of the water table to the rainfall events (Table1 & Figure 3). Therefore, it is obvious that the aquifer system, spread in the study area responds well within one/ two months lag of rainfall. It can also be observed that the aquifer response is maximum particularly due to the rainfall that occurs from October and November during which period contribution of rainfall to ground water is maximum and withdrawal is minimum.

The water table hydrographs against the rainfall show one/two month's time lag. It has been observed that the aquifer responds significantly to rainfall during October to January of each year. The

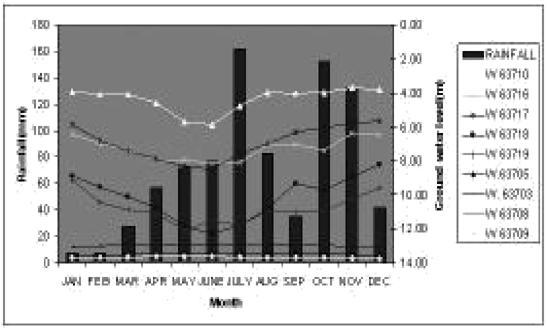

Figure 3. Average water level fluctuation with average annual rainfall from 1988-2008

independent variable, rainfall (r) and dependent variable, depth to water level (d) with one/more months lag to rainfall are plotted. Considering the mean of rainfall (r) and depth of water level (d), origin may be shifted to the point (r , d). Therefore, the new coordinates may be defined as R (= r - r) and D (= d - d).

The correlation coefficient (r) is defined as (Grewal,1993): $r \sum RD/n\sigma r\sigma d$ Where

R = Deviation from the mean r (= r - r),

D = Deviation from the mean d (= d - d),

σr = Standard deviation of r-series,

σd = Standard deviation of d-series and

n = Number of datasets of depth to water level corresponding to the rainfall

Results and Discussion

The rainfall occurred mostly during north east monsoon period. The water levels of unconfined aquifer in the study area with rainfall respond after one/two months of rainfall. The cross correlation co-efficient were determined between depth of water table and corresponding rainfall. The computed correlation coefficients are shown in Table 2. It clearly indicates that all the wells are responding well with

Table 2. Cross correlation matrix in between depth of water table and rainfall in different lag periods. (Jul-Jan)

Well No.	63703	63705	63708	63709	63710	63716	63717	63718	63719
Without lag	0.63	0.40	0.69	0.00	0.13	0.31	0.05	0.33	0.44
One month lag	0.83	0.81	0.63	0.34	0.33	0.65	0.84	0.59	0.53
Two month lag	0.60	0.25	0.04	0.57	0.22	0.45	0.67	0.09	0.02
Three month lag	0.30	0.68	0.48	0.63	0.07	0.04	0.22	0.36	0.29

one month lag followed by two months lag. The recharge is less after two months of rainfall. The correlation coefficient values plotted with corresponding lag of water table rises are shown in Figure 4.

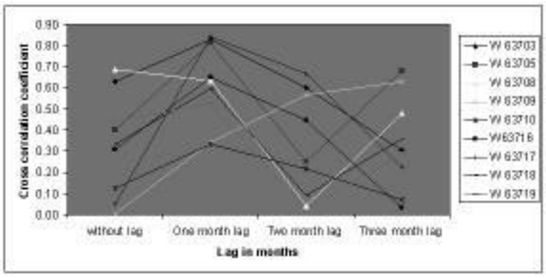

Figure 4. Plot of cross correlation coefficient in different lags.

By applying the cross-correlation analysis to water table variation in response to rainfall the following observations have been made.

- The time lags of 1-month and 2-month shows maximum response of the aquifer after rainfall.
- The amplitude of correlation decreases when lag increases/decreases in a systematic manner.
- The depth of the aquifer also governs the delay.

Based on correlation coefficient values, the zones of recharge were divided (Figure 5) as high recharge zone (r > 0.80), moderate zone (r = 0.60 - 0.80) and low recharge zone (r = 0.40- 0.60) and zone of poor recharge (r < 0.40).

Figure 5. Ground water recharge zone map by cross correlation method

This map obtained by cross correlation were checked with the thematic geo- morphological, land use, lineament and geology maps interpreted from satellite imageries generated by using GIS technologies (CE,SG & SWRDC report,2006) which gave satisfactory results.

Studies conducted by Mondal and Singh (2004) using cross correlation technique to determine the recharge response due to rainfall in Kodaganar River basin, Dindigul, TamilNadu revealed that one month time lag is required for response of the water table due to rainfall events and that the aquifer responds only to the rainfall during the period between October to December of each year and not to the total amount of rainfall.

Conclusion

In semi-arid regions of hard rock areas, groundwater occurs in shallow weathered zones. The rise in groundwater level is a direct consequence of precipitation, particularly in the monsoon season, when the groundwater withdrawal is minimal. The rise of water level at a particular place is characteristic feature of unsaturated zone. Therefore, there exists a definite relationship between the amount of rise in water level and precipitation for a particular region. In other words each zone is characterized by a parameter that correlates rise in groundwater level with precipitation. Higher correlation coefficient implies significant groundwater recharge characteristic or most favorable recharge zone. This fact has been well demonstrated by the groundwater level and rainfall data for in PAP basin of Tamil Nadu, a hard rock area and recharge zones were delineated. This technique is simple, but, yet reliable when compared to complex and time consuming conventional methodology of using hydrogeological, geophysical and geomorphological maps.

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